

# **POLARISED TARGETS TWENTY YEARS ON**

**G. R. Court**

**Physics Department, University of Liverpool UK**

**Polarised Targets – What is happening, was the title of a talk given at the 1982 Spin Physics Symposium also held at Brookhaven Lab. [ref]**

- **Main interest polarised protons and deuterons**
- **Most experimental data obtained with dynamically polarised solid state targets.**
- **Target technology well developed and mature**
- **Some new techniques involving gaseous state under development**

**What has been the progress over the last 20 years?**

**What is happening now and in the future?**

**[ref] G.R.Court , Proc. High Energy Spin Physics,  
Ed G.Bunce AIP No 95 (1982) p 464**

## POLARISED TARGET S – HOW

Solid materials containing required nucleons

- Apply high magnetic field (B) at low temperature (T)

Practical constraints :-

- Max usable B in range 2.5 to 5 T
- Min usable T in range 1 to 0.05 K

Negligible polarisation (P) in these conditions (TE)

Example – protons at  $B = 2.5\text{T}$  and  $T = 1\text{K}$  gives  $P = 0.0025$

Solution - DYNAMIC NUCLEAR POLARISATION (DNP)

- Introduce free electron spins weakly coupled to the nucleon spin system - with practical B and T electron P is very high.
- Transfer electron polarisation to nucleon system via microwave pumping giving high nucleon P

Intrinsic problems for practical targets

- Does NOT work with solid hydrogen (deuterium)
- Nucleon dilution factor always  $< 1$  in usable materials
- Deuteron polarisation always  $<$  proton polarisation
- Susceptibility to radiation damage
  - damage centres have free electron spins which can interfere with the DNP.

## TARGET MATERIALS

### Aims

- polarised protons and deuterons ( for neutron)
- High nucleon P – expt. error  $\propto P^2$
- Large nucleon dilution factor (ideal = 1)
- Low sensitivity to radiation damage.

### 1982 scene

- In general use

Chemically doped (to provide unpaired  $e^-$  spins) solids

- Monohydric alcohol ( $C_4H_{10}O \approx 14\%$  hydrogen)  
proton P up to 0.85 (deut.  $\approx 0.3$ )
- Dihydric alcohol ( $C_3H_8O_2 \approx 11\%$  hydrogen)  
proton P 0.85 to 1 (deut.  $\approx 0.45$ )

- Under development

Radiation doped ammonia

Proton P up to 0.9 (deut  $\approx 0.3$ )

$NH_3 \approx 17\%$  hydrogen

Radiation life time up to x 30 compared with alcohols.

- Interesting ideas

(i) Radiation doped lithium deuteride ( $^6Li D$ )

Both D and  $^6Li$  polarise

If  $^6Li \equiv ^4He + ^2H$  then dilution factor is large

(ii) Spin stabilised atomic hydrogen (Not possible for D)

Note - high density gas not DNP

## TARGET MATERIALS -contd.

### **Past 20 years and current scene.**

- Chemically doped materials still in mainstream use

Some recent new developments (see later)

- Radiation damaged ammonia – now the standard material for many experiments

Unpaired spin centre production for DNP depends on radiation chemistry - difficult to understand and control.

DNP friendly centres produced with irradiation in liquid nitrogen temp region (77 to 80K)

Proton (deuteron) P typically 0.85 (0.3) at 2.5T and < 0.5K and  $\approx 1.0$  (0.45) at 5 T and 1K

Deuteron polarisation increased by  $\approx \times 3$  with secondary irradiation (in beam) at 1K.

With DNP, all spins polarised -  $^{14}\text{N}$  has spin 1  
P calculable and measured.

## TARGET MATERIALS - contd

- Radiation damaged  ${}^6\text{LiD}$

Radiation chemistry more critical than ammonia  
Need very careful control of temperature during  
the irradiation (optimum  $\approx 185\text{ K}$ )

Long development programme  
First used in major experiment in 1995

- Other materials

A large range of high hydrogen materials ( typically Li  
and B compounds) investigated for DNP.  
- no significant improvement.

Some success with spin polarised atomic hydrogen  
giving thickness  $\approx 10^{13}$  protons  $\text{cm}^{-2}$ , the same order as  
storage cell gas targets - very difficult technology  
Not used in an experiment yet.

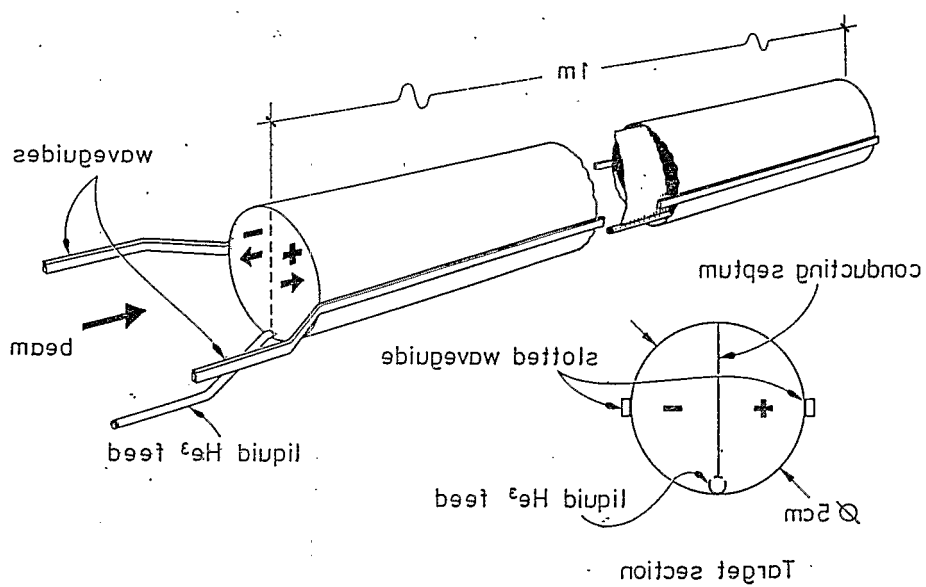
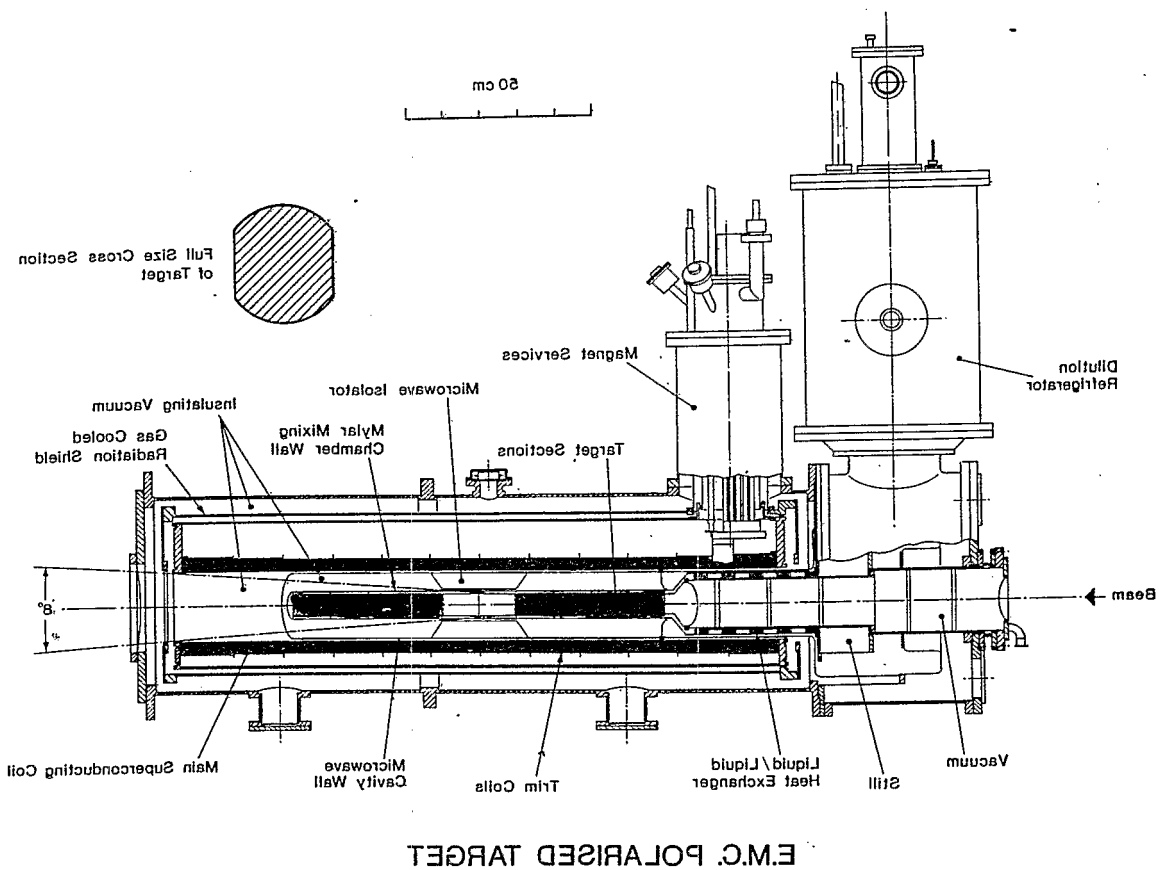
Brute force polarised HD - 17 T with  $T < 15\text{ mK}$   
(but operation at 1 T and 0.5 K)

$P_p \approx 0.8$ ,  $P_D \approx 0.38$  reported  
Only usable at low beam intensities

## SPIN PHYSICS EXPERIMENTS AND TARGET TECHNOLOGY

### Spin Physics scene 1982

- General Hadron Physics - typical target parameters
  - solid alcohol ( $10$  to  $100 \text{ cm}^3$ )
  - $B = 2.5 \text{ T}$  (some SC magnets),  $T = 0.5 \text{ K}$
  - Frozen spin mode for good access
    - Separate polarisation and operation
    - Operate at  $< 100 \text{ mK}$  and maybe lower value of  $B$ .
    - Only usable with low beam intensities.
- Nucleon spin structure measurements (measure  $g_1^P$  only)
  - (i) Electron scattering ( $20 \text{ GeV}$ ) at SLAC (E80 and E130)
    - Longitudinal spin direction only – SC solenoid
    - High beam intensity – radiation damage and beam heating problems. E130 used  $5 \text{ T}$  and  $1 \text{ K}$  to reduce beam heating effects.
    - Data consistent with naive quark-parton model.;
  - (ii) Proposed  $200 \text{ GeV}$  muon scattering at CERN (EMC)
    - Low intensity and large cross section beam
    - Large volume target ( $2 \text{ litre}$ )
    - Two sections in tandem with opposite polarisations
    - $2.5 \text{ T}$  SC solenoid - high power ( $2 \text{ Watt}$ ) dilution fridge.
    - Aim, increased  $Q^2$  and to lower  $x_{\text{BJ}}$ .

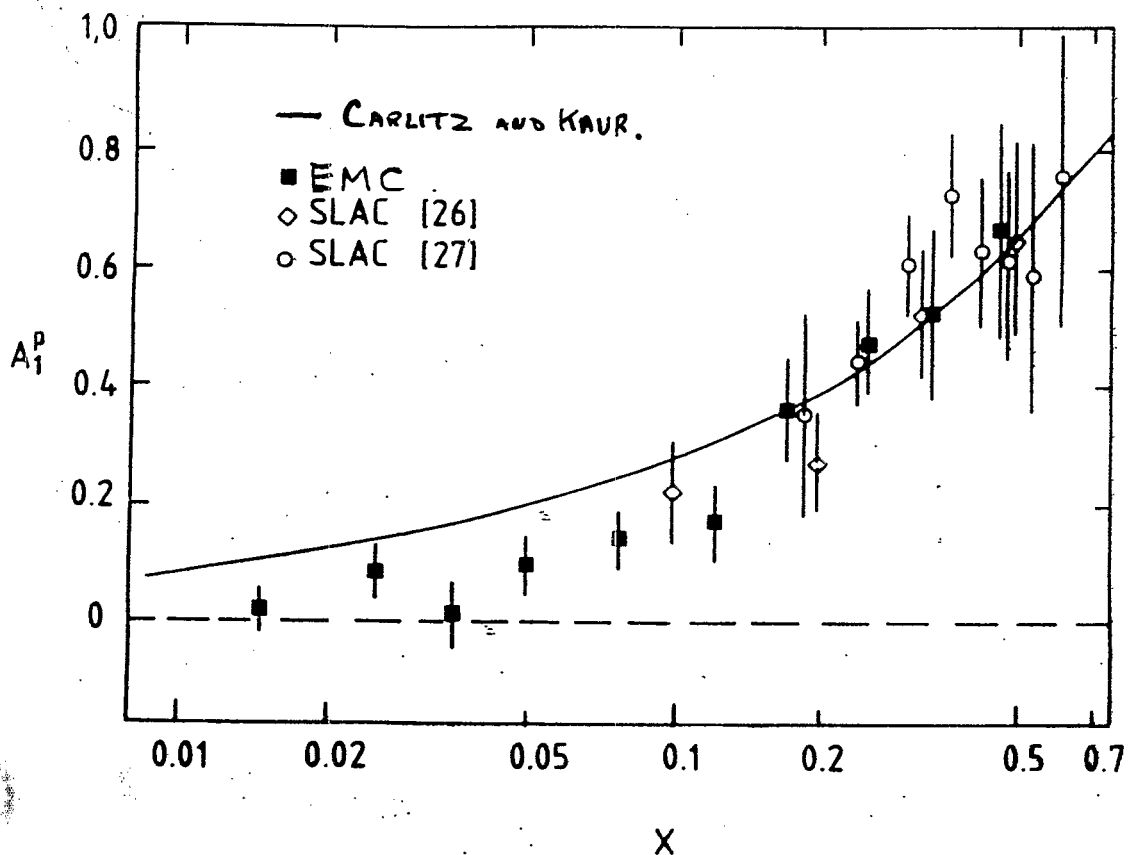


## SPIN PHYSICS EXPERIMENTS AND TARGET TECHNOLOGY contd.

### Spin Physics - past 20 years

#### Nucleon spin structure measurements

1. EMC measurement of  $g_1^P$ 
  - EMC target material –  $\text{NH}_3$  with  $P^P \approx 0.85$   
Data taking 1984/85 – publication 1989  
Now a classic result - paper holds citation record
  - Great theoretical interest - more experiments proposed
    - (i) check and improve  $g_1^P$  measurement
    - (ii) measure  $g_1^N$  - neutron target
    - (iii) measure  $g_{2^{P,N}}$



## 2. New proposals and experiments

### a) SMC at CERN

(i) with modified EMC target (1991 - 1992)

(ii) with new SMC target (1993 - 96)

Coils for transverse spin direction (in frozen spin mode) for  $g_2$ , and spin direction reversal.

Size increase to 2.5 litre

Materials - Butanol (14% H) for  $g_1^P$

$$\langle P^P \rangle = 0.86$$

- D - butanol (23% D) for  $g_1^N$  and  $g_2^N$

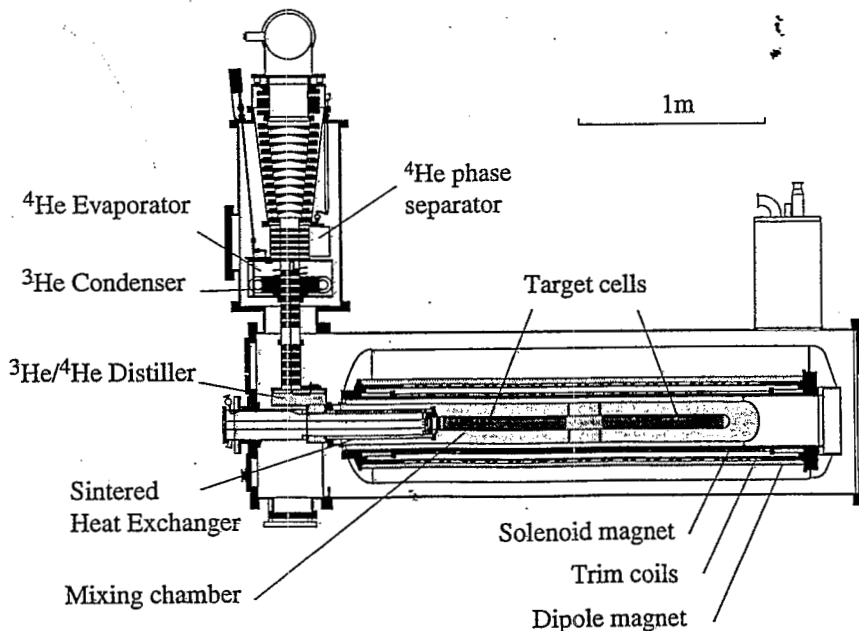
$$\langle P^D \rangle = 0.51$$

- Ammonia (17% H) for  $g_1^P$  and  $g_2^P$

$$\langle P^P \rangle = 0.8$$

Technical development -  $P^D$  raised by FM of microwave pump source - x 1.7 in D - butanol.

Problem - polarised spectator nucleon with  $\text{NH}_3$



Dilution refrigerator

Superconducting magnets

b) SLAC spin programme

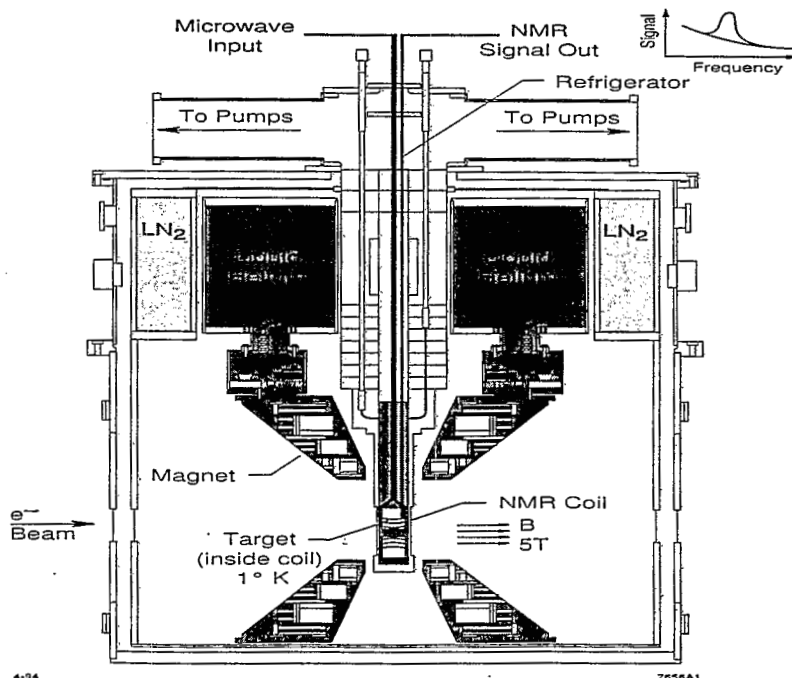
Similar to SMC - lower  $Q^2$  and smaller  $x_{BJ}$  range, better statistics

(i) E 142 / E154 -  $g_1^N$  with a  $^3\text{He}$  target neutron target

(ii) E143 -  $g_1^P, g_1^N$  with high intensity beam using  $\text{NH}_3$  and  $\text{ND}_3$  with  $B = 5\text{T}$ ,  $T = 1\text{K}$   
 Rad. damage major problem,  $P_{\text{init}}^P \approx 1$ ,  $\langle P^P \rangle \approx 0.7$   
 Secondary (in beam) irradiation improved  $P^D$  with and  $\langle P^D \rangle \approx 0.25$

(iii) E155 and E155x -  $g_1^P, g_1^N$  and  $g_2^{P,N}$  with  $\text{NH}_3$  and  $^6\text{LiD}$  with  $\langle P^D \rangle$  (and  $P^{\text{Li}}$ ) of 0.5

Spectator polarised nucleon problem - used  $^{15}\text{NH}_3$  and  $^{15}\text{ND}_3$  eliminates polarised neutron in  $^{14}\text{N}$ , improves polarisation measurement ( $^{15}\text{N}$  has spin  $1/2$ )



c) HERMES – gas target in storage ring

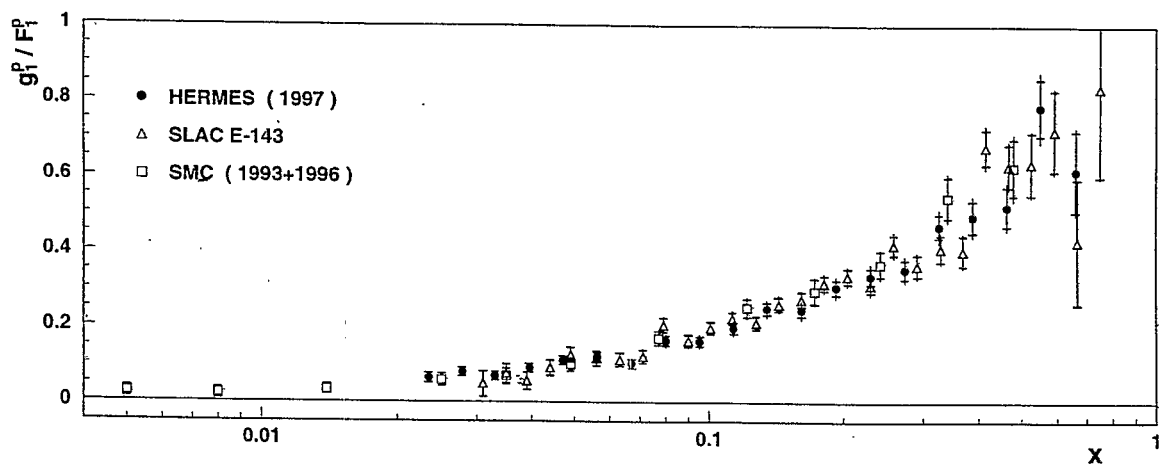
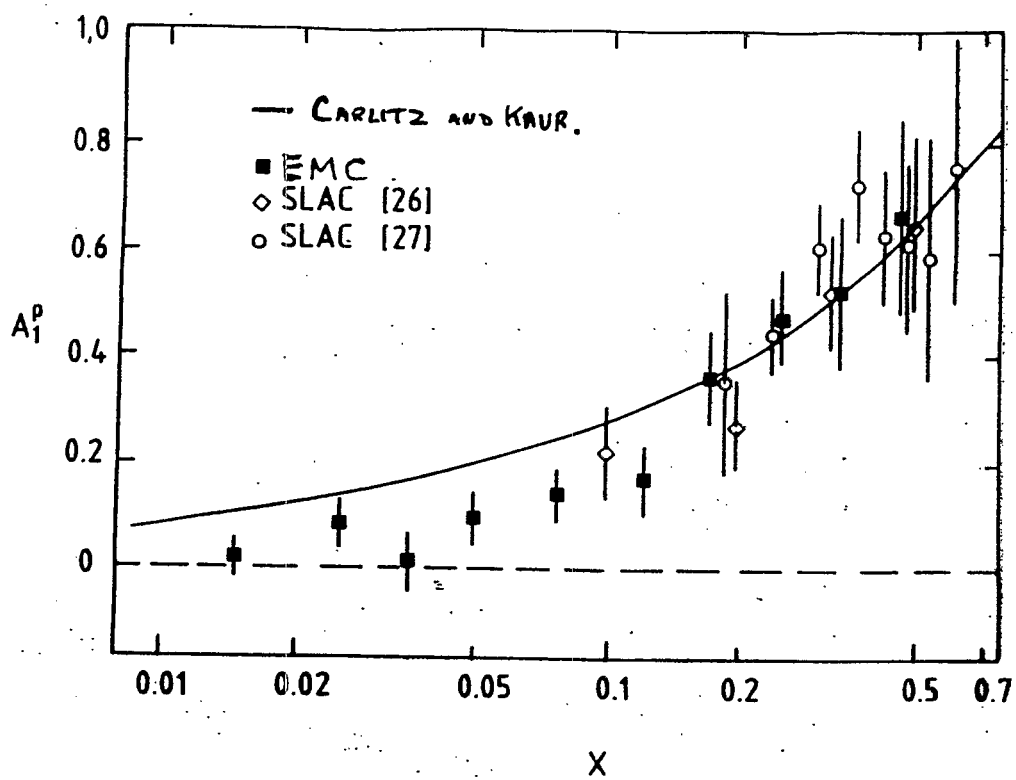
## **SPIN PHYSICS EXPERIMENTS AND TARGET TECHNOLOGY – CURRENT AND FUTURE**

### **Spin structure function measurements – current state**

- A large and very precise data set now exists.
- A large proportion obtained with solid state targets
- SLAC E142 and HERMES use the only non SS targets
- HERMES provides an important cross check on systematic uncertainties as all SS targets use NMR technique to measure target polarisation.
- Current experimental interest – polarisation of gluon

### **Experiments to measure the gluon polarisation**

- a) HERMES have made a preliminary measurement.
- b) COMPASS at CERN – currently data taking  
Measurement of the gluon spin distribution  $\Delta G/G$  (and other DIS parameters) using the SMC target with new magnet to give a higher experimental acceptance. Requires high nucleon polarisation so  $^6\text{LiD}$  with initial  $P$  values  $\approx 0.5$
- c) E161 at SLAC - approved experiment  
The gluon spin distribution using polarised open charm photoproduction.  
Also requires high nucleon polarisation so will use  $^6\text{LiD}$   
Planned to operate at 6.5 T and 0.3 K to get  $P^D \approx 0.7$   
Similar mechanical layout to previous SLAC targets.



## Other nucleon or nuclear spin structure experiments

Most 1982 frozen spin techniques - still in current use.

The frozen spin solid HD technology is in use in a low intensity photon beams at LEGS.

SLAC type target for 'nuclear physics region'

Examples - SLAC E 159 - GDH sum rule.

Uses  $\text{NH}_3$  and  $\text{ND}_3$  nuclear effects become more important.

- Jefferson lab electron and photon beam experiments

## Recent target material developments

a) The possibility of using a modified DNP process to get target material which operate at 77 K or higher.

Example –  $P^P$  of 0.3 in naphthalene ( $\approx 7\%$  H) at 77 K.

b) Introduction of chemical doping materials for DNP which are stable enough to be incorporated into plastic materials making thin foil and scintillating targets possible.

## Polarised Nuclear Targets

A property of DNP – all nuclei with spin in the material polarise. Hence a possible way to get polarised nuclear targets e.g  $^{14}\text{N}$ ,  $^{15}\text{N}$ ,  $^{13}\text{C}$ ,  $^{19}\text{F}$  and others. Also tensor polarisation (alignment) with spin 1 nuclei has been shown to be possible.

Examples –  $^{13}\text{C}$  target at LAMPF and  $^7\text{Li}$  target at PSI

## **Measurement of target polarisation**

Most SS targets in current use measure the target polarisation with NMR using a system originally developed by the Liverpool group for the EMC Target.

Typical systematic uncertainties in the range 2 to 5% depending on the operating conditions.

Improvements in statistical precision and target performance - increased significance of these uncertainties.

New method of using the Liverpool system reported - improves system linearity and signal to noise ratio, when critical factors.

Lower systematic uncertainties should be possible using this technique.

## CONCLUSIONS

- In 1982 the dynamically polarised solid state (DPSS) target played a dominant role in the experimental spin physics scene. Typically high  $P^P$  (0.85 to 1) and usable  $P^D$  (0.3 to 0.45) were obtainable in materials containing  $\approx 14\%$  protons.
- Over the last 20 years big improvements in materials for DNP have been made. The current best has  $P^P$  of 1 with 17% protons ( $\text{NH}_3$ ) and  $P^D$  of 0.5 with nominally 50% deuterons ( $^6\text{Li D}$ )
- $^6\text{Li D}$ , an interesting idea for DNP in 1982, has now been developed to a fully usable target material. Even higher  $P^D$  will be possible if higher target fields can be used.
- The improved materials have generally also been found to be less sensitive to radiation damage – serendipity!
- DPSS targets have played an important and critical role in the experimental study of the spin structure of the nucleon and will clearly continue to do so for some years to come.
- Gaseous state targets have also played an important, but complimentary role.
- DNP is a very flexible and versatile technique which should continue to have many applications in the future in both HEP and nuclear spin physics experiments.

Quote – final sentence in 1982 paper [ref]

'It seems likely therefore that that DNP in conventional materials will be with us for some time to come'.

It seems that this was correct - for 'sometime' now read twenty years or even longer.